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RESEARCH MEMORANDUM

REFLECTION OF SHOCK WAVES FROM SLOTTED WALLS AT MACH NUMBER 1.62

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

July 21, 1952

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HAFB 1288

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REFLECTION OF SHOCK WAVES FROM SLOTTED WALLS AT MACH NUMBER 1.62

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SUMMARY

A brief study was made of the effect of slots in a test-section wall on the reflection from the wall of an incident oblique shock wave at a free-stream Mach number of 1.62. The reflection was observed with an interferometer for various combinations of slot width, spacing, and contour. The reflections from the open and the closed portions of the wall, being at different angles to the wall, were not superposed and, therefore, did not cancel each other.

INTRODUCTION

When the tests reported herein were made, the use of slotted test-section walls had just been proposed (ref. 1), and the investigation and development of the slotted-wall wind tunnel for aerodynamic testing in the transonic-speed range was beginning at the Langley Laboratory. Although the purposes of the slotted-wall tunnel were to permit testing in the transonic range with less wall interference and to permit testing through the speed of sound without changing either nozzle or test section, there was also hope that it might be useful in the higher supersonic range.

In supersonic flow, when the surface of a wedge is at a positive angle with the free-stream direction, a shock wave is generated that turns the flow parallel with the surface of the wedge. When the shock wave is incident on the solid wall of the test section, the shock wave is reflected as a shock wave that turns the flow back into a direction parallel with the wall. The boundary condition is thus satisfied that the direction of flow must be parallel with the wall at the wall. If the air flow takes place in an open jet, the shock wave incident on the boundary of the jet is reflected as an expansion wave behind which the pressure is the same as the ambient pressure. The boundary condition is thus satisfied that the pressure in the jet at the jet boundary must be equal to the pressure outside the jet. If the wall is slotted, and thus both partly closed and partly open, the reflection of a shock wave incident on the wall might be expected to be composed of both shock waves and expansion waves.

It was realized that the expansion waves would lie at a smaller angle to the wall than the shock waves and that they would probably be spread out more, longitudinally, than the shock waves. It was felt, however, that there might be a possibility that some kind of interaction near or within the slots would tend to make the two kinds of waves cancel each other. The purpose of the experiments reported herein was, therefore, to explore the possibility of such wave cancellation in a slotted-wall test section. Several slot widths, spacings, and contours were used in order to provide information on the relative effectiveness of variations in slot geometry on possible wave cancellation.

APPARATUS

The tests were made in a jet that issued from a nozzle outlet that was 3 inches square and in which the free-stream Mach number was 1.62. The jet was open, or free, on three sides and the pressure in the free-stream was therefore atmospheric. On the fourth side, a side wall of the two-dimensional nozzle was extended, and in this side wall the slots were located. Figure 1 shows schematically the location of the slots with respect to the nozzle. The slots were made either by milling them in the steel side wall or by cutting out a section of the side wall and replacing it with a section made up of wooden slots. Figure 2 shows cross sections of the various slot configurations that were used. The under sides of the slots were open to the atmosphere. In the free stream above the slots a double-wedge airfoil was supported by a sting. The forward part of the lower surface of the wedge was set at an angle of attack of 5°, and the shock wave from the leading edge was incident on the slots.

A Mach-Zehnder interferometer was used for making observations of the flow. The field of view of the interferometer is indicated in figure 1. Interferograms were taken that showed the shock wave incident on the slotted wall and the reflection of the shock wave from the slotted wall. The interferograms were used only for qualitative observations, inasmuch as obtaining accurate quantitative results was not feasible. The principal reason was that, where the sides of the shock wave intersect the vertical boundaries of the jet, the pressure behind the shock wave is greater than atmospheric pressure; this condition causes expansion waves to be propagated back into the jet at an angle to the jet axis. Behind these expansion waves the density is reduced. On account of these waves, the optical path length through the jet varies along the axis of the jet and, consequently, accurate quantitative analyses of the flow appear not to be possible. The variation in path length shows up as a tilt in the fringes, but the expansion waves that cause the variation cannot be seen, as the interferometer is looking at them broadside and not end on. Because of this axial variation in optical path length, the density at any point cannot be compared accurately with the density at some point that is any appreciable distance from it in an axial direction. Correct qualitative observations can, however, be made of changes that take place within a short distance. Shock waves and expansion waves can easily be recognized and their relative intensity obtained.

RESULTS AND DISCUSSION

Figure 3 is an interferogram taken with no flow. The adjustment of the interferometer is such that the interference fringes are horizontal when there is no disturbance in the test section. In the flow interferograms that are presented subsequently, an increase in density at any location over the density at some reference location is shown by a downward displacement of the fringes at the location with respect to the fringes at the reference location. An upward displacement of the fringes at any place indicates a decreased density there.

Figure 4 is an interferogram of the flow when the shock wave from the leading edge of the wedge, of which the lower surface is at 5° to the flow, is reflected from a solid, unslotted wall. This figure shows that the density jump across both the incident and the reflected waves is fairly large. The fringe shift across the waves is so large that an individual fringe cannot be followed across the waves.

For the next test, three $\frac{1}{8}$-inch-wide slots with square corners and spaced 1 inch on centers (fig. 2(a)) were milled in the wall in the direction of flow, and the shock wave was reflected from this slotted wall. Figure 5 shows the flow pattern. The intensity of the reflected shock wave is not much less than that of the shock wave reflected from a solid wall. Although a slotted wall that is one-eighth open has a ratio of open to closed area that is of the correct order of magnitude for use in a slotted-wall, transonic wind tunnel, the ratio is much too small for the open area to cause a significant reduction in the intensity of reflected shock waves in supersonic flow when a small number of rather large slots with square corners are used.

A calculation was made to determine what ratio of open to closed area would result in no change in average density across the reflection, with the density averaged through the jet in a direction perpendicular to the free-stream flow direction and in the direction of the light beam. Average density was chosen as the quantity to be held constant across the reflection because the interferometer responds to the average density through the jet and, if there were no change in average density before and after the reflection, there would be no fringe shift across the reflection.

It is easy to calculate from shock-wave and expansion-wave theory that the average density behind the composite reflection would be the same as the density ahead of the reflection if 1.37 inches of the 3-inch jet width is solid wall and 1.63 inches is open. Across the reflection from the closed part of the wall the calculated density ratio is 1.19. Across the reflection from the open part of the wall the calculated density ratio is 0.84. The calculated ratio of average density across the composite reflection is then unity. A slotted wall was prepared by milling four slots 0.422 inch wide in the wall. The slots were spaced 0.684 inch on centers (fig. 2(b)). This arrangement gave a slotted wall that had slightly less solid wall than the amount calculated. The total width of the solid part was 1.31 inches and of the open part was 1.69 inches. The interferogram of the flow for this wall is shown as figure 6. As was expected, the shock wave from the closed part of the wall and the expansion wave from the open part were not superposed, but the shock wave was ahead of the expansion wave. Figure 6 shows further that the fringe shift and the density change across the shock wave from the closed part are less than the fringe shift and the density change across the expansion wave from the open part of the wall. These results indicate that, at least in the region near the wall, complete elimination of reflection from a slotted wall cannot be obtained from supersonic flow, and that the effective width of an open portion is greater than its geometric width.

The jet used for the present tests was too small for the reflection from the slotted wall to be observed at large distances from the wall. The present tests, therefore, do not show how much the reflection changes in intensity at comparatively large distances from the wall. Reference 2, however, indicates that at about 3 inches from the wall both the compression and the expansion disturbances from the slotted wall have become too weak to be visible with the schlieren apparatus that was used for observing the flow.

Instead of four rather wide slots, as were used for figure 6, a set of fourteen narrow slots was also tested (fig. 2(c)). These slots were 0.12 inch wide and were spaced 0.22 inch on centers. The total width of the solid part was 1.32 inches and of the open part was 1.68 inches. The resulting interferogram is shown in figure 7. The narrow slots give the same qualitative results as the wide ones. The expansion wave causes a greater density change than the shock wave and the shock wave is at a steeper angle to the flow than the expansion wave.

In all the slotted-wall configurations discussed previously, the portions of the solid wall between the slots had square contours, but rounded and pointed contours were also used. A wall was made with three $\frac{1}{8}$-inch slots spaced 1 inch on centers, and the solid portions were rounded off into circular arcs of 45°, as shown in figure 2(d). An interferogram of the flow is shown in figure 8. The intensity of the expansion wave is about the same as that of the shock wave. The effective area of the three $\frac{1}{8}$-inch slots (fig. 8) is much greater than that of the three $\frac{1}{8}$-inch square-corner slots used for figure 5.

A slotted wall with twenty 0.05-inch slots, spaced 0.155 inch on centers (fig. 2(e)) with the solid portions rounded into circular arcs, was also used (fig. 9).

A slotted wall with twenty 0.05-inch slots, spaced 0.155 inch on centers (fig. 2(f)) with the solid portions pointed to form 60° angles was also tested (fig. 10).

With these last two slot configurations the area that was effective in causing the incident shock wave to reflect as an expansion wave was much greater than the area that was effective in causing the incident shock wave to reflect as a shock wave, as is shown by the strong expansion waves. Furthermore, these expansion waves turn the flow into the slots, as is shown by the fact that practically all the boundary layer goes into the slots.

CONCLUSIONS

The following conclusions can be drawn from the experiments on the reflection from a slotted wall of a shock wave in supersonic flow:

1. No significant reduction in the intensity of the reflection is produced when only one-eighth of the wall area is open.

2. The effective width of an open portion with square corners appears to be greater than its geometric width.

3. Pointing or rounding the solid portions between slots makes the effective area of the open portion much greater than when the slots have square corners.

4. The expansion waves and the compression waves from a slotted wall lie at different angles to the wall, and, therefore, do not cancel each other, at least in the vicinity of the wall which was the only region investigated.

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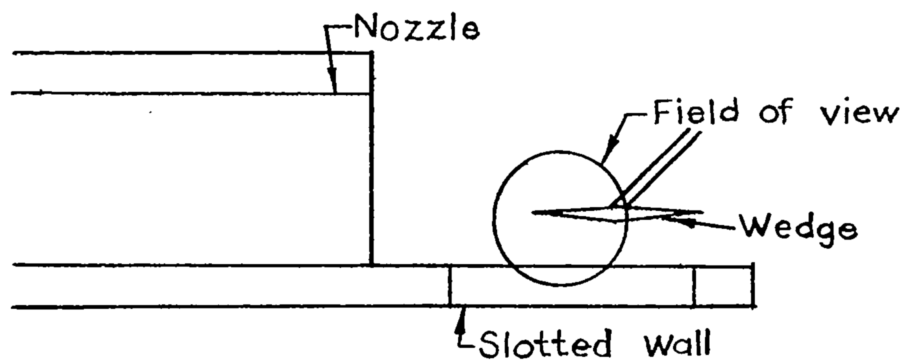
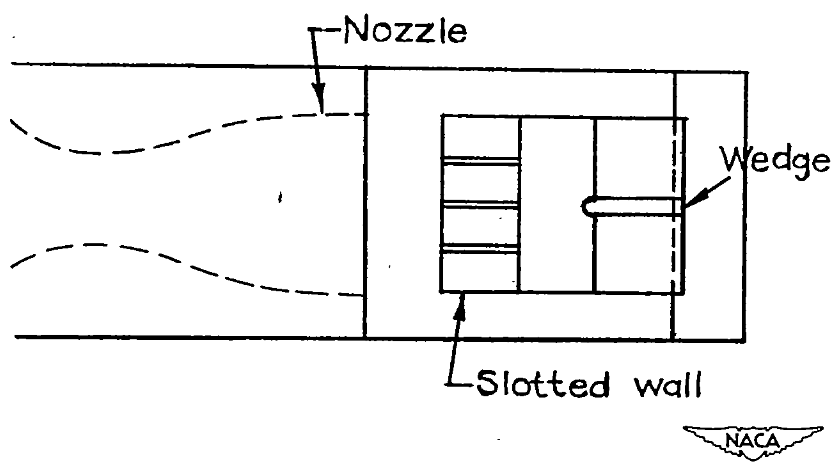
1. Wright, Ray H., and Ward, Vernon G.: NACA Transonic Wind-Tunnel Test Sections. NACA RM L8J06, 1948.

2. Douglass, W. M.: Slotted Test Section for a Low Supersonic Mach No. Wind Tunnel. USCAL Report 10-2-1, Progress Report Contract NOa(s)10585, Item 2, Univ. Southern Calif., Aero. Lab., Oct. 10, 1949.



(a) Elevation.



(b) Plan.

Figure 1.- Arrangement of nozzle, slotted wall, and wedge.

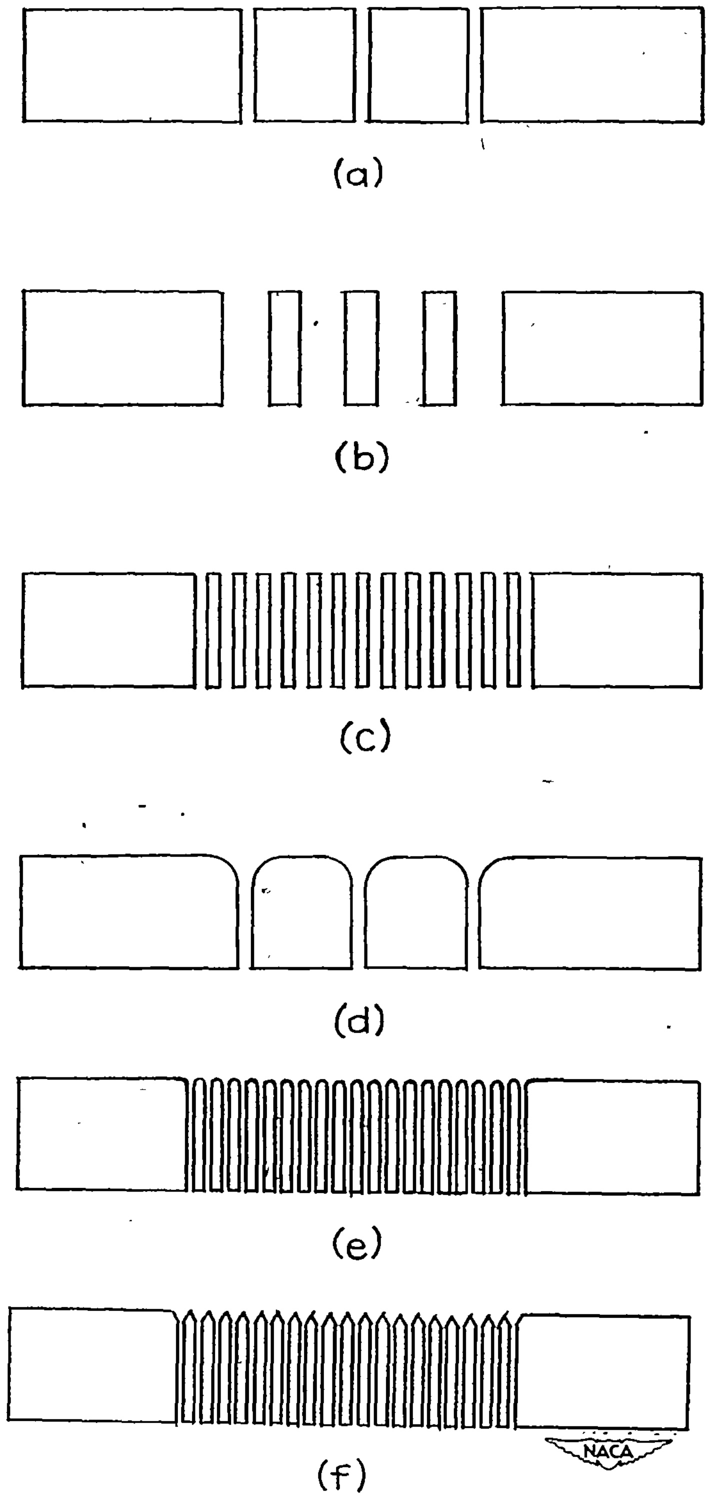


Figure 2.- Cross-sectional views of slotted-wall configurations.

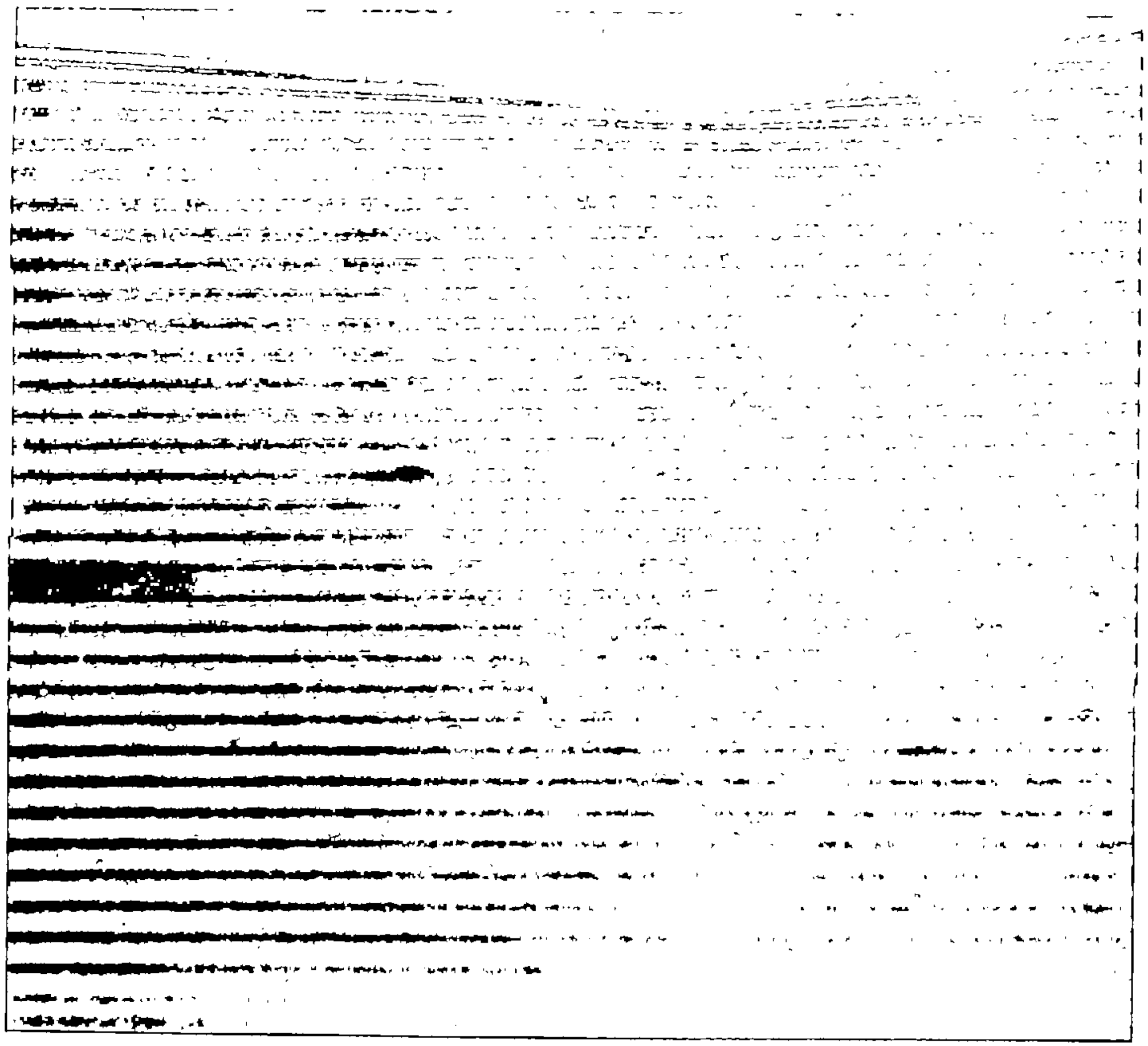


Figure 3.- Interferogram without air flow.

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Figure 4.- Interferogram showing reflection of shock wave from solid wall.

Figure 5.- Interferogram showing reflection of shock wave from wall with three $\frac{1}{8}$ - inch square slots (fig. 2(a)).

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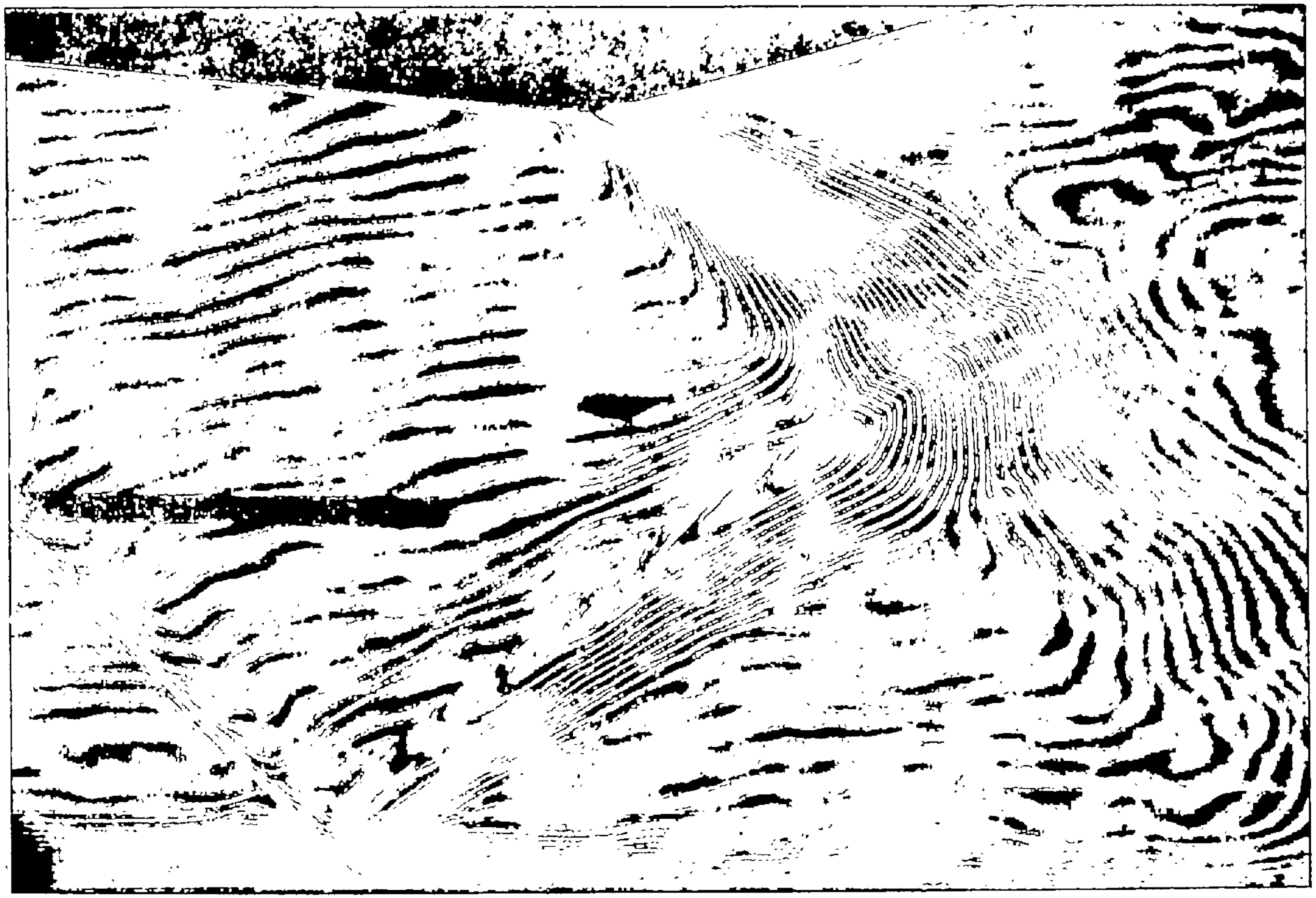

Figure 6.- Interferogram showing reflection of shock wave from wall with four 0.422-inch square slots (fig. 2(b)).

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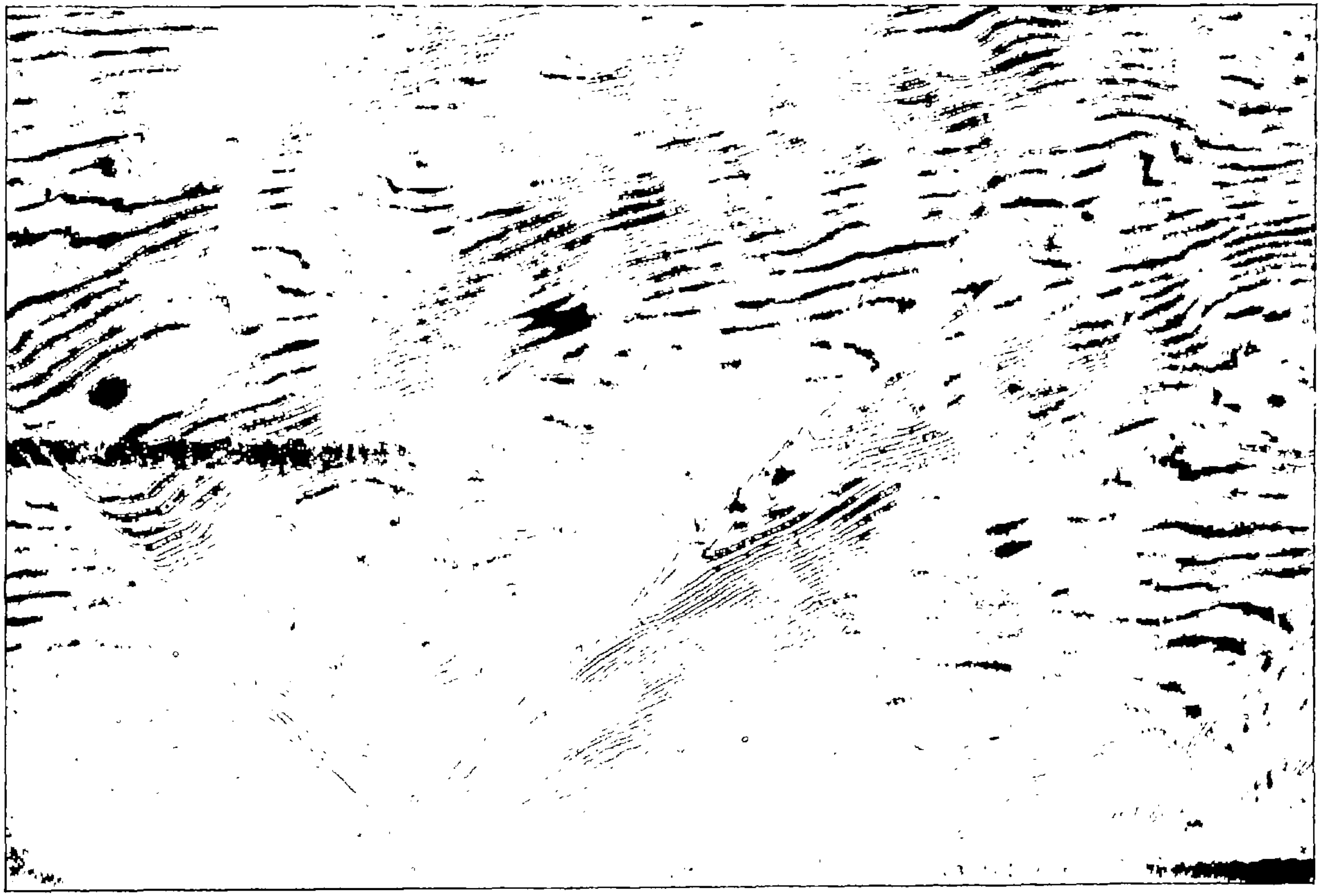

Figure 7.- Interferogram showing reflection of shock wave from wall with fourteen 0.22-inch square slots (fig. 2(c)).

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Figure 8.- Interferogram showing reflection of shock wave from wall with three $\frac{1}{8}$-inch rounded slots (fig. 2(d)).

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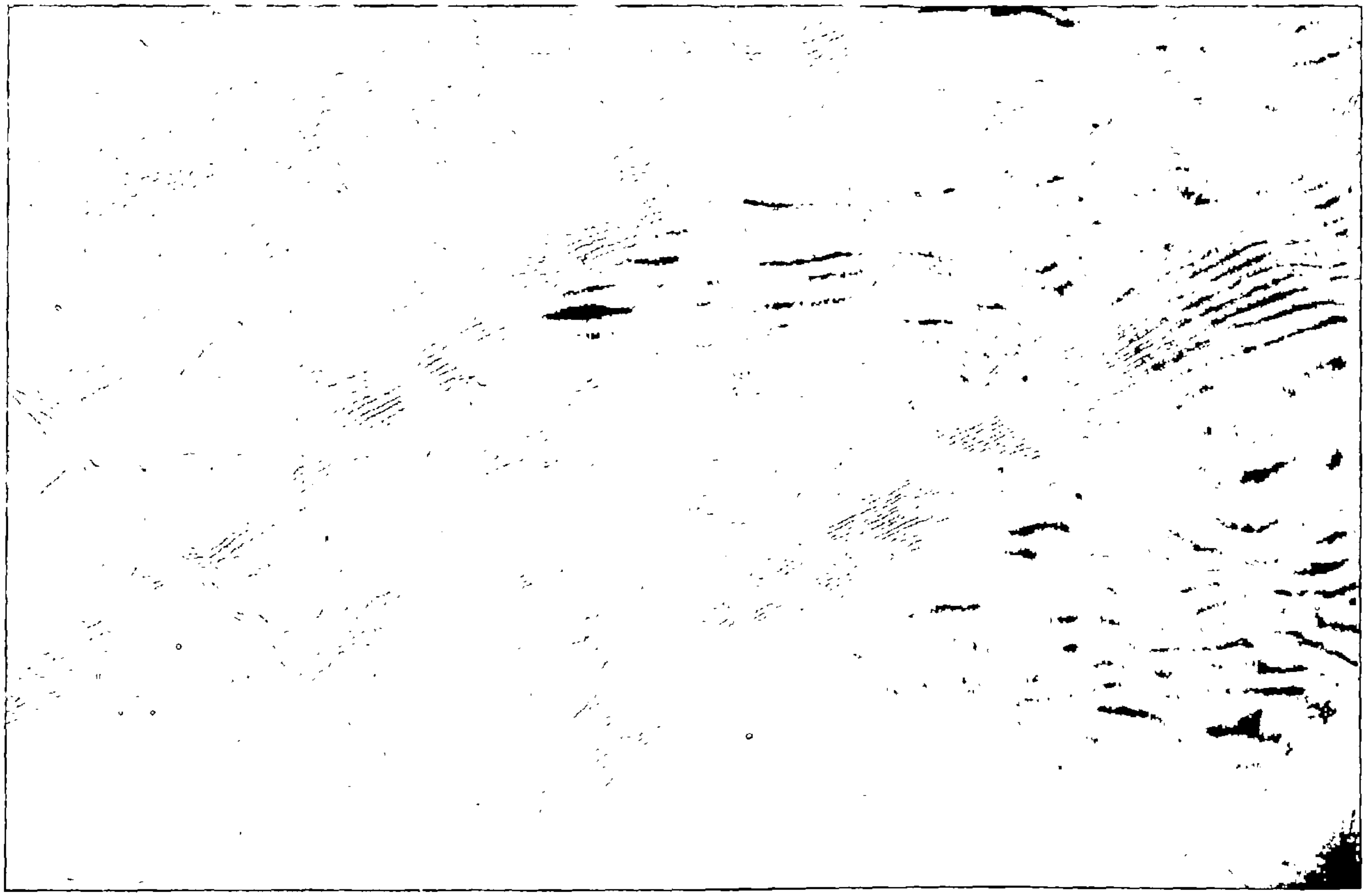

Figure 9.- Interferogram showing reflection of shock wave from wall with twenty 0.05-inch rounded slots (fig. 2(e)).

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Figure 10.- Interferogram showing reflection of shock wave from wall with twenty 0.05-inch pointed slots (fig. 2(f)).

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